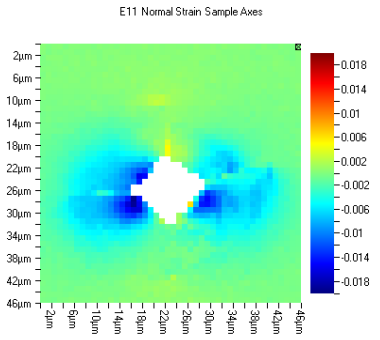
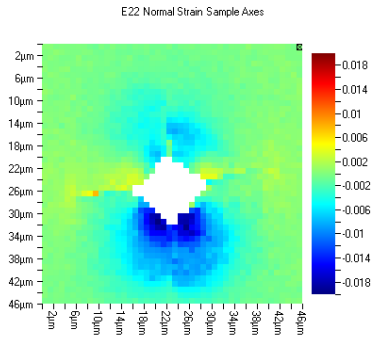
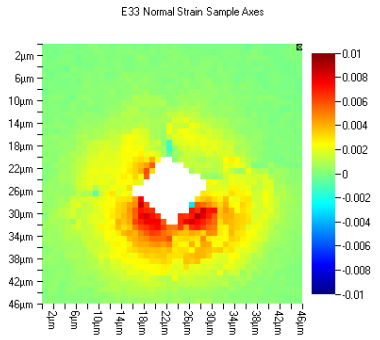
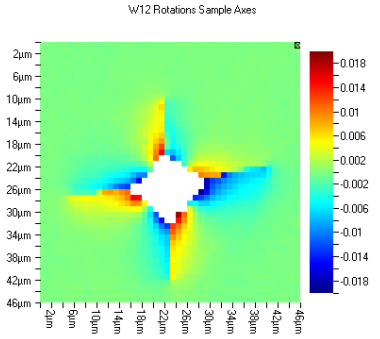
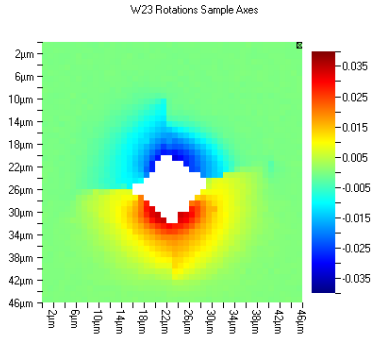
Cross Court 3 User Manual

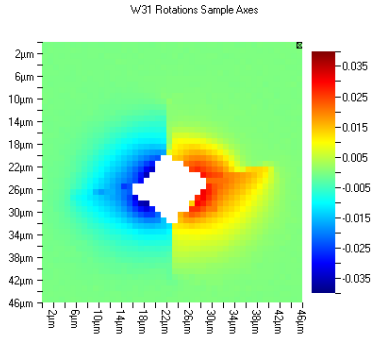


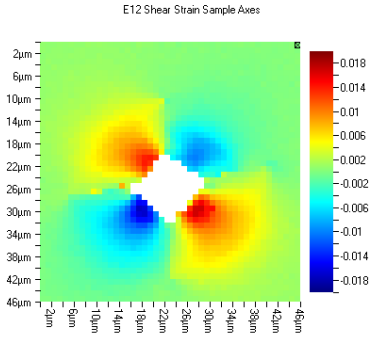


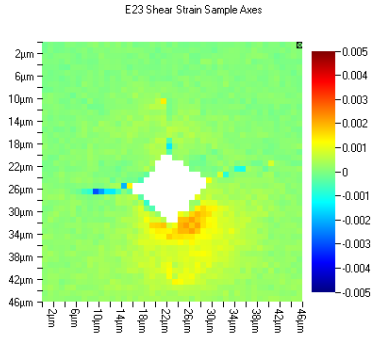


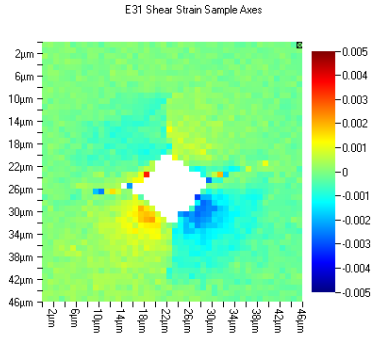


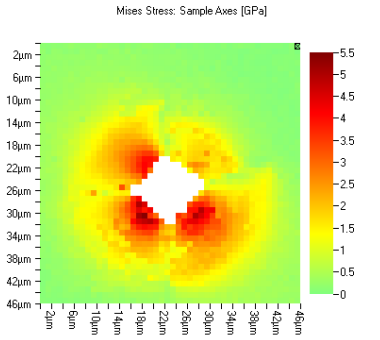


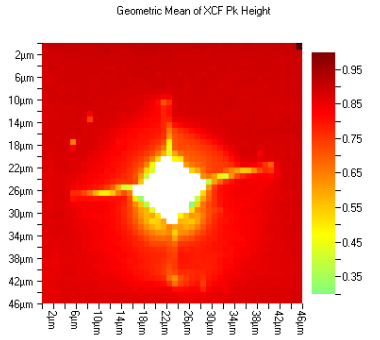


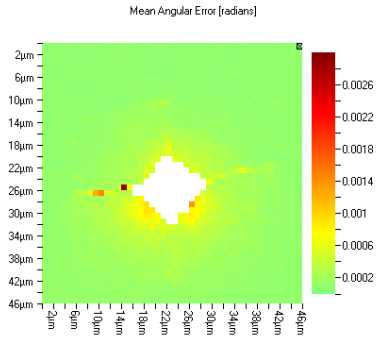












EBSD Based Strain Measurement Software

User Guide for the CrossCourt 3 Strain Measurement Tool

Contents:

1 – Before You Start

- 1.1 Software Specification.
- 1.2 Computer Requirements
- 1.3 Installation Instructions
- 1.4 Notes for Users of CrossCourt 2
- 1.5 Overall Description of the Software
- 1.6 Practical Considerations when collecting EBSD patterns

2 – Getting Started

- 2.1 Loading a Project
- 2.2 General Software Layout

3 – Single Crystal Case

- 3.1 Project Page
- 3.2 Materials
- 3.3 Thresholding
- 3.4 How to Select and Display a Reference Pattern
- 3.5 Pattern Display
- 3.6 Regions of Interest
- 3.7 Filter Settings
- 3.8 Process Panel
- 3.9 Results Pages
- 3.10 Display Page

4 – Polycrystalline Case

- 4.1 Finding Grains
- 4.2 Grain Tolerance Angle
- 4.3 Find References

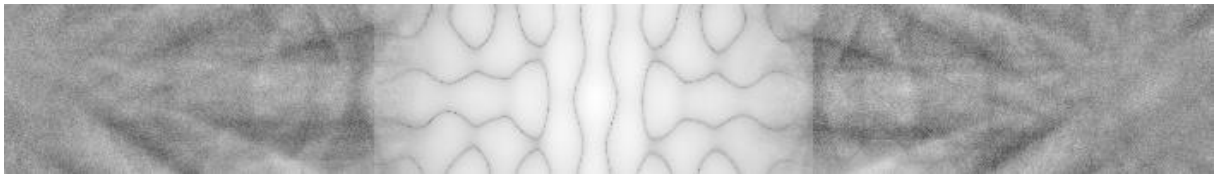
5 – Additional Functions

- 5.1 Right Click on Map context Menu
- 5.2 Right Click on Linescan Context Menu.
- 5.3 Menu Items
- 5.4 Beam Shift Calibration
- 5.5 Load Folder

© BLG Productions Ltd 2010

6 – Matlab Data Structure for CC Analysis

Section 1 – Before You Start.



1.1 Software Specification

The software produced by BLG productions and titled Cross Court 3 provides a means of measuring small distortions and rotations of electron backscatter diffraction patterns obtained from near perfect crystalline material. This is achieved by comparing an EBSD pattern from the target area with one taken from unstrained material within the same crystal. These rotations and distortions can be measured to a precision of 2 parts in 10000, dependant on the quality of the EBSD pattern. In the program it is assumed that the measured distortions result from elastic strain in the volume giving rise to the patterns or to a rigid body rotation at zero strain or to a combination of the two. The program includes analysis to extract components of the strain tensor and rigid body rotations. The precision of these measurements is also in the ±2 parts in 10000 regime. The analysis includes use of the fact that the surface examined is in plane stress and the assumption that the strain beneath it is constant within the sample volume. The results obtained must be used with full recognition of this latter assumption.

It should be noted that any artefacts in the recorded pattern arising from scratches on the imaging phosphor, defects in the camera, uneven sample surface or poor sample preparation can also give rise to apparent distortions and rotations and care must be taken to avoid them. See appendix 1 for more details. Further, if there are significant changes in the contrast of the diffraction pattern caused amongst other factors by sample topography, specimen charging, shadowing or large atomic number differences between reference area and target area then there may be some loss of sensitivity.

1.2 Computer Requirements

- Display Size at least 1280 x 1024 pixels
- Windows XP/Vista or Windows 7 (32 or 64 bit) and a copy of Microsoft Excel 2003 or later.
- CD Drive.
- Multiple CPU cores recommended
- RAM of at least 2 gigabytes

It is recommended that a hard drive of at least 80 Gb. be installed and a computer speed of greater than 1.8 GHz be used.

For maps of more than 255 columns, Excel 2007 or higher is needed to save the projects in BLG format.

For analysis of large datasets of polycrystalline materials with more than 10 grains, it is recommended that a 64bit version of windows be installed. For very large datasets a 64 bit version of Excel is also necessary.

Please note that the language settings on both the Operating System and Excel must match – this includes the number format.

1.3 Installation Instructions

CAUTION: Do not insert the dongle until after the software has been installed.

Insert the CD. The setup program should start to run automatically. If it does not, run the file **setup.exe** that is found in the root directory of the CD.

The computer should ideally be connected to the internet. If the installation program fails to detect the necessary Microsoft .NET runtime libraries, it will download the appropriate files from the internet and install them. However, if an internet connection is not available a copy of this (dotnetfx.exe) can be found on the CD. Continue following the on-screen instructions for installation of the Cross Court 3 software package and drivers for the security dongle.

The first time the dongle is inserted to any USB port, the 'Found New Hardware' wizard will start. Follow the instructions and allow Windows to automatically find the drivers for the dongle.

1.4 Notes for Users of CrossCourt 2

CrossCourt 3 (CC3) is an expansion of the CrossCourt 2 strain measurement Tool. The main improvements are as follows:-

Importing of EBSD project files from the EDAX/TSL and Oxford/HKL systems, allowing the software to utilise stored project information such as Euler Angles, Phase, Pixel position etc. Such information means the software can process maps (both rectangular and hexagonal scans) as well as line scans and non spatial collections of data.

These data sets are plotted graphically in a manner suitable to the scan type. Results can be output as bitmaps for use in reports or exported to Excel for further analysis. Correctly formatted Excel datasets (BLG Projects) can be reloaded into CC3

Cross correlation is now performed across multiple processors (if available) using an improved engine to CrossCourt 2. This can speed up the processing of data sets by a factor of almost the number of processing cores (i.e. 2 cores -> almost twice as fast, 4 cores -> almost 4 times as fast. etc)

CC3 is designed to allow processing from more than one reference point so that more than one grain can be analysed at a time in polycrystalline and poly-phase materials.

CC3 can analyse the orientation information in the project file and decide whether cross correlation is possible between 2 data points. The angular difference between the two points must be less than half that covered in a region of interest. From this, grains or sub-grains are distinguished and treated separately. The reference patterns used in each grain can be selected automatically using image quality, best fit or confidence index or manually.

All measured shift data is held in active memory so that subsequent changes made to pattern centre position, elastic coefficient values, scan parameters, reference pattern etc will be reflected in the results without having to re examine the EBSD patterns.

Notes for Users of Crosscourt 3.0

There are 2 major changes between Crosscourt 3.0 and Crosscourt 3.1 as far as the user is concerned – The most important of these is that the definition of a Grain has changed, to become more in line with the standard EBSD Grain definition – see the Polycrystalline section for more information.
The second change is an internal change of data format which allows CrossCourt 3.1 to manage far larger data sets than Crosscourt 3.0

Notes for users of Crosscourt 3.1

The naming of the BLG format has changed. Project files are now have the extension blgp and Results files now have a blgr extension – Previously all files had a simple .blg extension. Old blg files can be renamed by changing the extension.

1.5 Overall Description of the Software

The CrossCourt software package uses cross-correlation based techniques to measure the relative shifts between EBSD patterns caused by small lattice rotations or elastic strains.

Comparisons are made between a reference pattern, representing a point of zero strain and a number of patterns taken from the area of interest.

There are 3 stages of the analysis,

1/ Calibration and Preparation.

In some respects this is the most important section. Good quality data leads to good quality results and it is worth spending time optimising the pattern collection. The user is referred to the separate manuals issued by EDAX_TSL and OXFORD_HKL for details as to the procedures adopted to carry out the procedure.

2/ Measurement of Pattern Shifts.

Once the EBSD patterns are transferred from the data collection software used, i.e. OIM_DC or Channel 5, and loaded into CrossCourt3 the software measures the relative shifts of small selected Regions of Interest (ROI) between each pattern and another selected as a reference pattern. The ROIs are selected either automatically or manually and the shifts are measured in pixels. The results from this are displayed graphically and can also be exported to a BLG Project File (based on an Excel worksheet).

3/ Calculation of Relative Stresses and Strains.

A minimum of 4 ROIs are needed to calculate the distortion tensor. Normally up to 20 ROIs are used to oversample and the best fit distortion tensor is calculated.

The pattern centre values and specimen to screen distance values read from the data collection project files are used to calculate the distortion tensor in the reference axes of the sample surface. The lattice distortion matrix is then split to provide the Strain tensor (Normal & Shear strains) and Rotation tensor (rigid body rotations).

Given further information about the orientation of the crystal and the elastics constants of the materials, the stress tensor is calculated.

1.6 Practical Considerations when collecting EBSD patterns

1/ Collection of High Quality EBSD Patterns.

The most important ingredient for successful strain measurement is high quality, high resolution EBSD patterns. These should always be collected at the maximum camera resolution for best results.

Pattern quality can generally be increased by (see below for more details) :-

- Use a camera with a detector containing at least 1000x1000 pixels and preferable with 12 bit gray scale resolution.
- Increasing the exposure time of the camera to the point where the brightest point in the image is almost saturated. This would correspond to an intensity level of 4096 in a 12 bit camera. Do not over expose. (Long exposure times however may lead to problems associated with specimen drift)
- Increasing the electron beam current (this may reduce spatial resolution because of the increased electron probe size.)
- Tilting the Sample to 75º for stronger EBSD pattern contrast. However, this will increase the electron probe footprint on the specimen surface and so add uncertainty as to where the pattern originates.
- Having a bright and scratch free phosphor.
- Selecting an appropriate electron beam voltage. Higher voltage improves pattern contrast but increases the sample depth of beam penetration.

2/ Avoid Scratches on the Phosphor

Any scratches or other blemishes on the phosphor represent areas of static content when comparing images. Static content may cause a true shift between strained and reference images to be smaller than it really is or even result in a zero shift measurement. Ideally, the phosphor screen should be in perfect condition.

The normal EBSD procedure of subtracting the background image of the phosphor from all recorded images of the EBSD pattern can have several advantages in this respect. It not only boosts the contrast of the patterns but may also remove phosphor defects. However, it is not always successful and good background images may be difficult to obtain, especially if the sample is a single crystal. In certain circumstances (e.g. in the case of measurements near an edge of a sample where electrons emitted from both of the surfaces at the edge contribute to the EBSD pattern) there may be such a change in pattern contrast that erroneous strain measurements can result.

3/ Avoid Over Saturation of the Pattern

If the patterns contain areas of over saturated pixels (especially the background pattern used for background subtraction), these will represent static features in the pattern and can cause an incorrect measurement of zero shift just as is the case for phosphor blemishes.

4/ Good Vacuum & Clean Samples

Significant contamination of the sample, by the generation of a thin film of carbon deposit on the surface, drastically reduces both the pattern quality and the ability to

make precise and accurate strain measurements. Using clean samples and anti contamination devices such as a liquid nitrogen cold finger is recommended.

5/ Number of Pixels in the Pattern

Obviously, if a pattern is taken with the highest resolution that the camera can provide, then more precise and accurate shift measurements are obtained. However, patterns taken at a higher resolution take proportionally longer to expose, which means that issues such as sample drift and beam contamination become more apparent. Some compromise between quality and speed may become necessary. Such compromises can be tolerated in cases where the focus of the experiment is not on elastic strain, but on rotations caused by plastic strain.

6/ Calibration

It is necessary to know the EBSD pattern centre and specimen to film distance i.e. the standard calibration data for interpreting EBSD patterns. This information is stored in the project files for the datasets but must be manually entered in the case where no project file exists.

The calibration routines in TSL OIM DC and Channel 5 software package can be used for this. .

The accuracy of the measurements depends on the accuracy of the calibration data provided. The calibration parameters are required to enable conversion of the directly measured shifts of the EBSD pattern within an ROI, which are in units of pixels, to an angular measure made with respect to the EBSD pattern centre. This calibration is essential for calculation of the strain tensor.

7/ – Pattern Centre Position. Specifically the value of Y* is important. If the sample is too low with respect to the phosphor screen then the spread of the spray of back scattered electrons will be centred low down the phosphor screen which means that the signal at the top of the screen will be weak and the results from ROI centred there will be very noisy and will degrade the overall performance of the calculations.
Try and adjust the height of the stage so that the spray of electrons is centred on the centre of the phosphor screen.

8/ Choice of the Reference Pattern

The reference EBSD pattern should be taken from a region known to be strain free. All other patterns will be compared to this pattern so that it should be of as high a quality as possible. It may not be known precisely if the selected region for the reference pattern is actually strain free. In this case although the precision of the technique remains, the strain values measured will not be accurate. All relative measures will have an accuracy and precision at the stated 2 parts in 10000.

In the mapping facility used in CrossCourt3 it is possible to set the reference pattern to be used both before and after the strain tensor and rotation tensor have been calculated. The before calculation reference patterns can be input manually or automatically using different criteria.

For manual input the user may wish to choose a point far away from a known point of strain, e.g. an indentation point, crack or grain boundary triple point in a polycrystalline material. The selection can be on the basis of the quality of the EBSD pattern for example how sharp it is or how well a simulated pattern overlay the actual pattern.

For automated reference pattern detection these same criteria can be used, in which case the software will search through data provided in the project files of the EBSD pattern indexing routines of TSL or HKL and search for the best pattern(s) as reported using their internal measures. Often the reference patterns found by these routines are not at the centre of grains for example, where the strain might be thought to be least, but closer to a grain boundary. In this case the user has the option to override the automated choice.

After strain measurement has been performed strain maps are presented. Inspection of these maps may then reveal a more likely location for the reference pattern. For example, at the centre of a region that shows no strain gradients over several microns for all strain components. (Alternative procedures are currently under investigation).

9/ Correction for beam movement.

When the electron beam of the SEM is moved across the sample there is an inherent and identical shift of the EBSD pattern across the phosphor screen. If large enough, generally more than 3 microns, the software will interpret this as a rigid body rotation. For this reason the reference pattern should be recorded from an area as close as possible to the area of interest. If beam movements of more than 3 microns are made, in a line scan or a map for example, then a beam movement correction procedure must be applied. The calibration method to facilitate this procedure is described at the end of this manual. However, it is best performed at the outset, immediately after familiarity with the software has been achieved.

10/ Keep the Experimental Conditions the Same for All Patterns.

The patterns collected must all be of the same image size and must all be collected under the same microscope conditions.

11/ Specimen to Screen Distance

The best experimental arrangement for taking measurements is to have the phosphor screen close to the sample collecting a wide solid angle of the diffraction pattern.

12/ Data Scan Collection

For the collection of the actual data set to be analysed, we recommend using an automated line scan or area scan generated by your EBSD collection software. It is first necessary to initialise the recording of patterns at each point in the video page. When you select the format of the image, always select 12 bit tiff images if possible. In the data collection page select line scan for line scan images or square grid option if recording an area image

If available, collecting and averaging more than frame at each point in the data set, makes a large difference to the quality of the data collected. This improves the signal to noise ratio in the patterns collected and leads to less noise in the strains calculated.

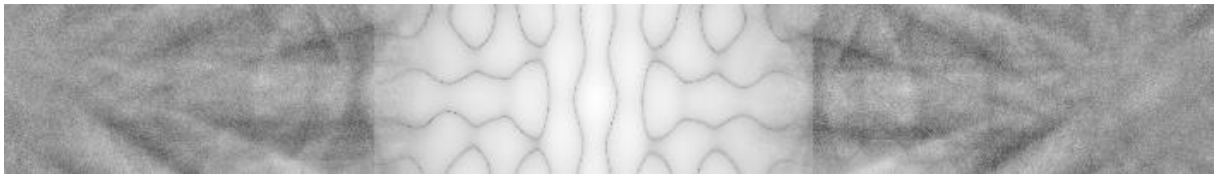
13/ A note about Euler angle settings

Each of the EBSD manufacturers uses a different default frame of reference for the Euler Angles. Crosscourt automatically rotates these into the frame of reference used by Crosscourt.

However, if the Euler data is collected in a non-standard frame of reference, Crosscourt will apply the default correction anyway which leads to the mixing up of the normal strains. This is because the Euler angles are only used in the rotation of the

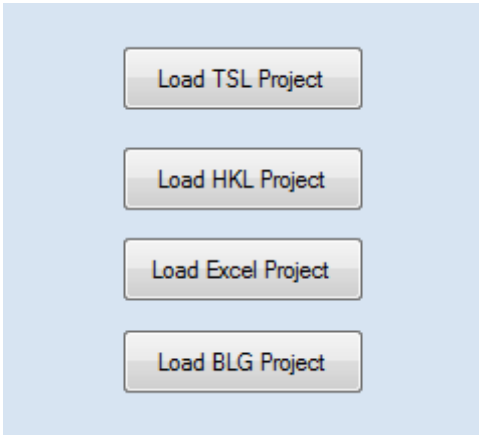
Elasticity coefficients which are used to set the traction free condition (i.e. S33 the stress normal to the surface is zero) so that all 9 tensor components can be calculated. If the wrong frame of reference is used, the stress is set to zero in a different plane and the normal strains are not calculated correctly.

Section 2 – Getting Started.



2.1 Loading a Project

When the software is started the welcome screen is displayed. One the left hand side is a panel containing 3 buttons as shown:-



The Load TSL Project button opens a dialog box allowing the user to search for an EDAX/TSL project file with the name '*project_name*.osc', where *project_name* is the name of the project. CC3 will be expecting the file to be alongside a folder that is also called *project_name*. This folder should contain the EBSD pattern image files ideally as Tiff files. This is the standard EDAX/TSL way of saving the datasets. Please refer to your EDAX/TSL documentation to find out how to save the EBSD patterns collected during a scan.

The Load HKL Project button opens a dialog box allowing the user to search for an Oxford project file with the name '*project_name*.ctf', where *project_name* is the name of the project. CC3 will be expecting the file to be alongside a file called *project_name*.crc as well as a folder that is called *project_name*Images. This folder should contain the EBSD pattern image files usually as JPEG files. Please refer to your Oxford/HKL documentation to find out how to save the EBSD patterns collected during a scan and how to create a '.ctf' file containing the project information (Orientations etc).

The Load Excel Project button can be used to reload datasets that have been previously saved to Excel using the 'Output | Save As' option as detailed later.

The Load BLG Project button is used to load *.blgp projects, which is a proprietary format used by Crosscourt to save and reload data.

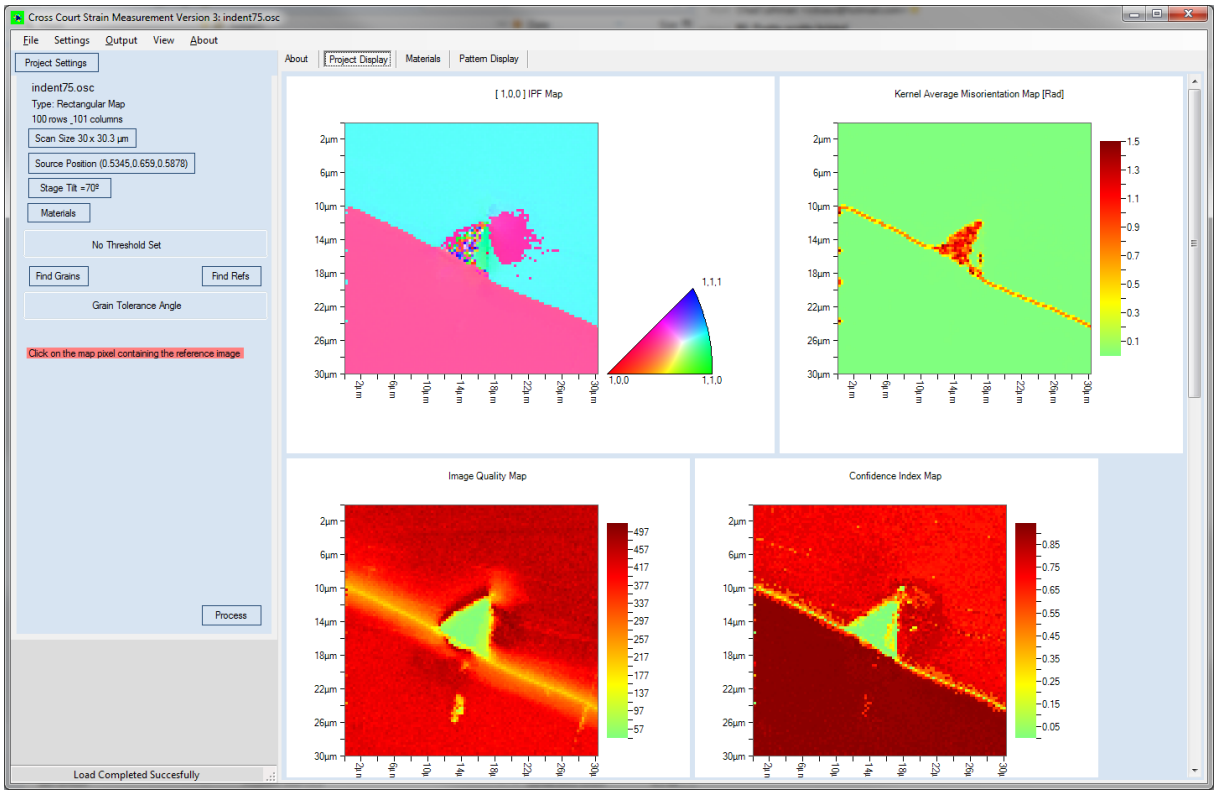
These options are also available from the 'File | Load Project' menu item on the main menu bar.

In addition is the 'File| Load Folder' menu item. This allows the user to select a folder containing only EBSD patterns. These may have been recorded as a separate line scan or as a set of patterns that have no defined relationship with each other– this is discussed later in Section 5.5.

2.2 General Software Layout

Once the project file has been successfully loaded the Project Page is shown on the left hand side of the application. On the right hand side of the application there are four tabs "About, Project Display, Materials, Pattern display". Initially, the Project Display page is shown, containing all maps and any line scans gleaned from the project files.

The illustration below is for data obtained from an EDAX_TSL project file. The maps shown are IPF, Kernel Average Misorientation (KAM), Image Quality and Confidence Index.



On the left hand side is the 'Project Panel' (see Section 3.1)

On the right hand side, project maps of the following types are displayed.

Cross Court Title	HKL/Oxford Title	TSL/EDAX Title
Kernel Average Misorientation	n/a	n/a
Image Quality	Band Contrast	IQ
Confidence Index	MAD	CI
Fit	Band Slope	Fit

Other IPF Maps are also displayed and it is possible to display maps of the Euler angles using the Settings menu. Also use the Settings menu to switch between degrees and radians.

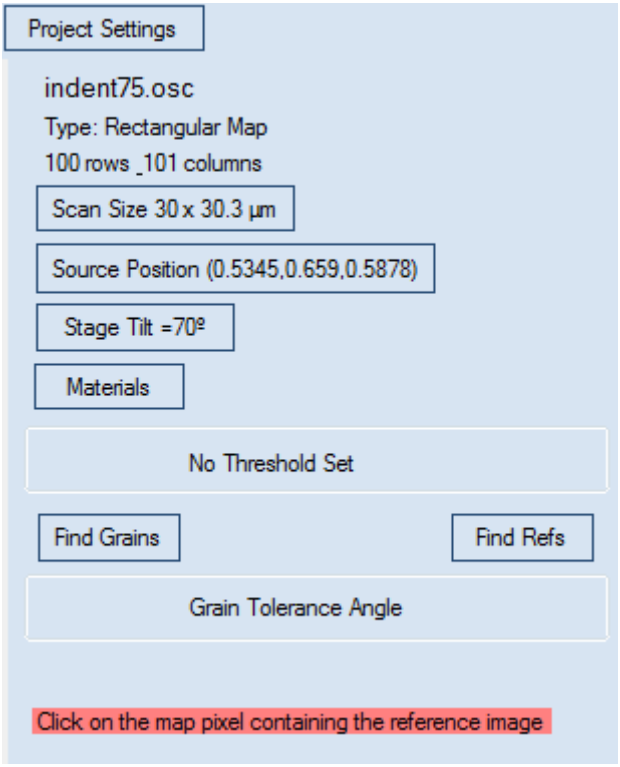
Right Clicking on the maps/graphs will show a context sensitive menu the functionality of which is detailed in Section 5.1 & 5.2.

This manual initially considers the case of a single crystal (section 3) and later describes the extra controls used with poly-crystals (section 4).

Section 3 – Single Crystal Case

3.1 Project Page

This Page initially displays information about the Project that has been loaded.



At the top is a Project Settings button that can be used to re-open this page. As analysis progresses, more buttons become visible here.

The labels just below this, show the name of the project file that has been loaded, the type of scan collected (i.e. line, rectangular or hexagonal scan) and the number of rows and columns in the data set.

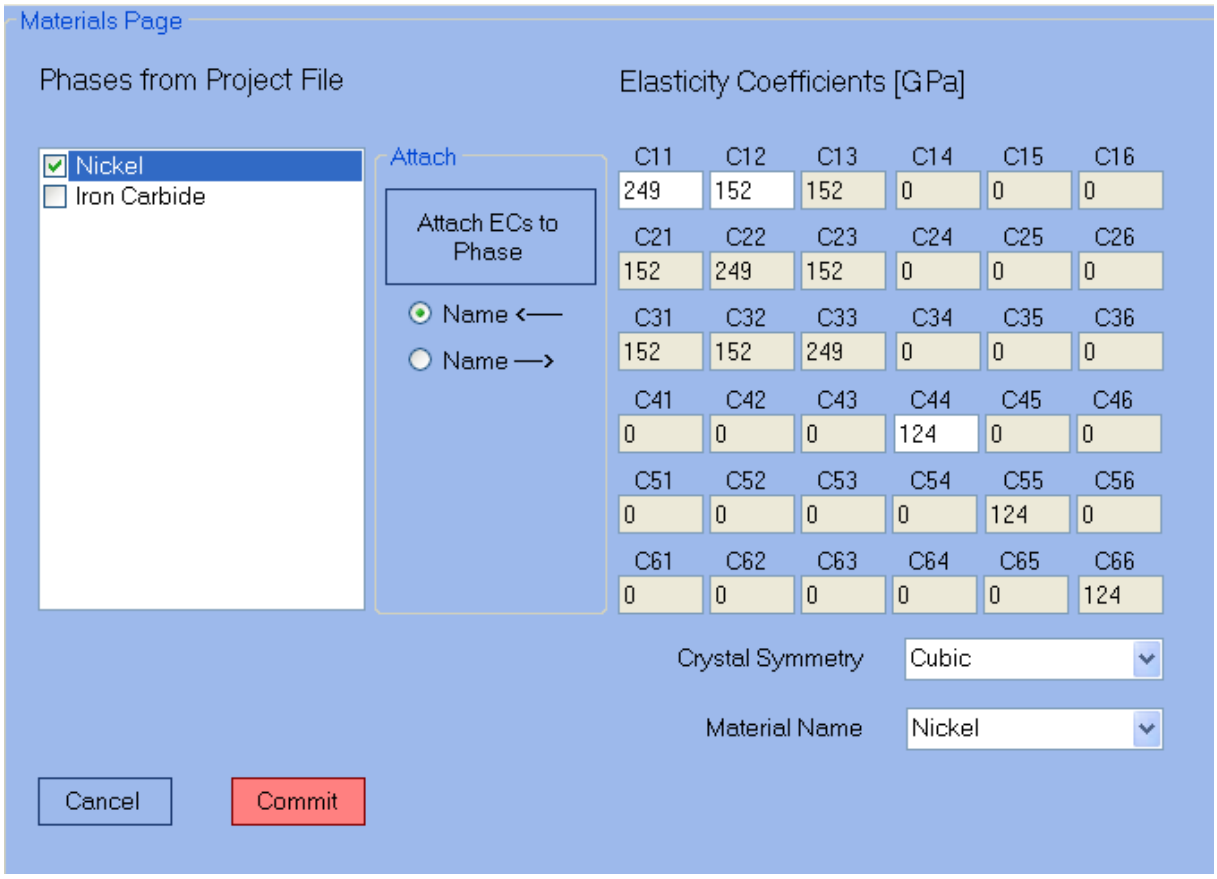
Below these are a number of buttons. Each can be clicked to launch a dialogue box to edit the values displayed. If the button is a red colour then the values stored are not valid and should be altered accordingly

. The buttons are:-

- Scan Size – click this button to edit the spacing of the collection points in microns.
- Source Position – this is in image units – i.e. one unit is equivalent to the height of the image. Oxford/HKL images are trimmed to squares so image height = image width.
- Stage Tilt - this is the angle between the sample surface and the horizontal. This value defaults to 70˚ when no information is present in the project file – as is the case with EDAX/TSL files. See also Camera elevation Tilt in the Settings Menu.
- Materials – this button is described in the following section.
- The remaining buttons, Find Grains , Find Refs and the Grain Tolerance Angle section are only applicable if a polycrystalline or multiphase crystal is being investigated. See the polycrystalline case in section 4.

© BLG Productions Ltd 2010

3.2 Materials



It is necessary to ensure that the appropriate elastic constants are loaded into the software for the materials of interest. If no name or conflicting data is loaded the Materials button will appear red and the cross correlation analysis can not be run fully until the correct data is loaded.

When the Materials button on the Project Page is clicked, the above Materials Page is displayed on the right hand side of the application.

On the left of the Materials page is a list of the phases loaded from the project file. Those phases with a ticked box next to them have automatically been associated with a set of Elasticity Constants (ECs) stored by CrossCourt.

The stored list of ECs can be accessed by using the drop down box (Material Name) at the bottom right of the page.

If it is required to assign a stored set of ECs to a particular project phase, first highlight the project phase in the left hand list. Next use the material name drop down box to select the desired set of ECs. The Attach ECs to Phase button will now associate the material phase with the chosen ECs. The 'Name' radio buttons can be used to update the phase name with the ECs name or vice versa. If the project phase is a commonly used one, it is recommended to update the ECs material name so that association is automatic in future.

To enter a new set of ECs, firstly select the desired Crystal Symmetry from the drop down box. This will allow the input of only those ECs that are independent and will allow propagation of dependent ECs across the matrix.

Next manually type in the values of the independent ECs. Once a value has been changed a new button will appear labelled Attach ECs As New Material. Click this once all ECs have been entered correctly. Enter the name of the new material into the dialog that appears. The new material will appear at the end of the materials list. Use the methodology described above to assign the new material to a project phase.

- Once all phases are assigned ECs the 'Commit' button should no longer be red and must be clicked to return the display to the Project Display correctly

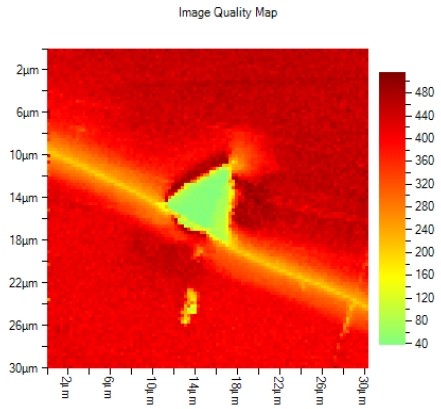
Often spare phase descriptions are included in the project file, though those phases are not present in the scan. If this is the case, attach ECs for any materials to the project phase – as there are no patterns, from these phase descriptions, the attached ECs are never used.

3.3 Thresholding

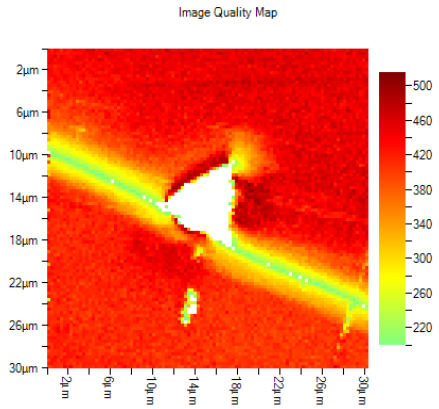
Next in the Project Panel is a panel initially marked ‘No Threshold Set’-No value need be input here. However, maps (or graphs) containing information from the project file are displayed on the right hand side of the page as shown above.

Thresholds are a useful device for removing low quality data from the dataset – For example the map shown below shows the Confidence Index map for an indent experiment. The area underneath the indent gives low quality EBSD patterns (hence the low Confidence Index) and such data will produce erroneous strain values.

A project threshold level can be set to ignore all data with a value below it by left clicking, (depress the left button of the mouse) on the colour scale of a map or the vertical Y axis of a graph. In the case of line scan the threshold value can be entered manually using the right click menu (Section 5.2).



Before Thresholding



After Thresholding (at IQ = 200)

Once set the details of the threshold are displayed within the panel and a “CLEAR” button becomes visible there to allow the threshold to be cancelled. Note that thresholds can be set using any map or graph and that all thresholds (except Mean angular error see Section 3.9) reject lower values. No project information is lost when thresholding, so multiple attempts can be made.

The Clear button on the project page can be used to reset any project threshold.

Individual data points can be removed from the project by right clicking on the particular data point and selecting ‘Remove Current Data Point’ from the context menu. This does not set any threshold value. The data can be reinstated by clicking the clear threshold button.

There is another opportunity to set a second threshold later on using the Quality Results from the Cross correlation process.

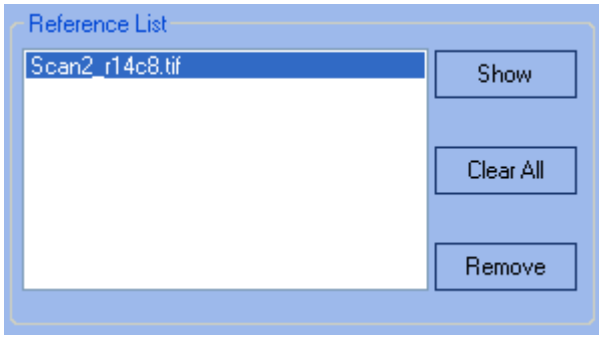
© BLG Productions Ltd 2010

3.4 How to select and display a Reference Pattern.

Unless a polycrystal is being examined and the Find Grains button has been pressed a red warning is displayed to click on a data point in one of the displayed images that you wish to use as a reference point. That is, the EBSD pattern from that point is to be used as the reference pattern against which all other measurements of strain will be measured. The point chosen should be one of zero strain. If it is impossible to select a point 'by eye' then one can use the point of best fit, highest quality or highest confidence index. The values of these parameters for any given data point are displayed at the top of the relevant map. More than one point can be chosen in which case strain maps will be drawn using each reference point in turn. It should be noted however that following calculation and display of the maps new maps can be drawn using a new reference selected from any one of the maps. The new maps are calculated by calculating the strain tensor of each point by, subtracting from the old values, the values of the selected new reference point as calculated using the previous reference point.

For the maps (including hexagonal maps which are not shown), left clicking on a map data point will not only select the data point as a reference, but also mark it with a cross.

In the case of the linescan graphs, left clicking on a point on the curve will choose that point as a reference. Alternatively right click on the graph and choose the 'Choose Reference Manually' and enter the number of the desired reference point.



Once a reference has been selected, the Reference List is displayed on the project page.
Clicking the Show button will display the selected EBSD pattern on the Pattern Display tab (see Section 3.5) on the right hand side of the application.

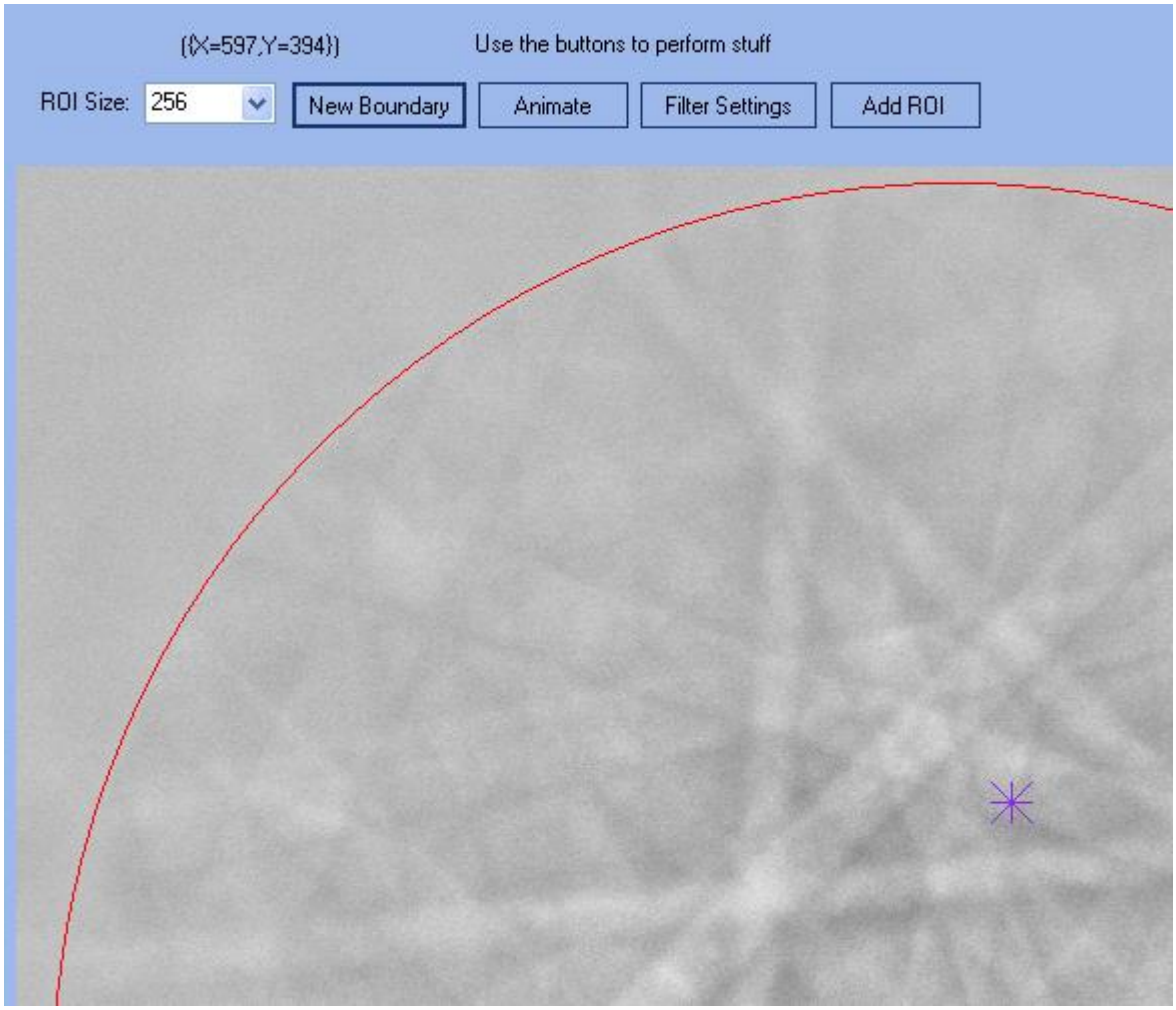
The Clear All button will remove all references from the list whilst the Remove button will only remove the highlighted reference.

After the reference pattern(s) have been selected it is still necessary to set up the Regions of Interest (ROIs) to be used in the measure of the distortion of a pattern with respect to the reference pattern. This is done with the pattern displayed as set out next.

© BLG Productions Ltd 2010

3.5 Pattern Display

The EBSD patterns can be displayed in several ways. Press the "Pattern display" tab at the top of the screen, right hand panel. It can be called from the Reference list by clicking the "show" button. Alternatively, right click on a particular map pixel and choose Show Pattern from the context menu.
A section of the page is shown below.



Right Clicking on the pattern shows a context menu with 2 options. One allows you to save the pattern as a bitmap. The second toggles the display of Regions of Interest.

The pixel position of the mouse is shown at the top of the page to the left of the file name of the image shown. A set of buttons are shown below it, ROI size, New Boundary, Animate, Filter Settings and Add ROI. Overlaid on the pattern are the pattern centre (purple 'star') and the current phosphor boundary (red circle).

We start with setting a new boundary.

A new boundary can be set with the New Boundary button. Click it and then click on 3 points on the boundary. The boundary is primarily used to control the region used in the automatic placing of Regions of interest (ROI) around the phosphor (see below). It should be drawn so as to include as much of the pattern as possible yet avoid the edges of the phosphor which often contain micro scratches which would affect the determination of the displacement tensor.

The Animate button will cause the software to loop through all the EBSD patterns collected and is useful for visually assessing their quality. This process can be stopped using the Abort button.

The Filter Settings button brings up the Filter Setting Dialog; see Section 3.7 for more information.

Clicking the Add ROI button starts the process of adding Regions of Interest.

3.6 Regions of Interest

A Region of Interest (ROI) is an area of the pattern used to perform a single cross correlation calculation.

The size of the ROI is set using the drop down box at the top left. The sizes are limited to multiples of 2 (e.g. 128,256 etc.) so that the Fourier analysis can be fast.

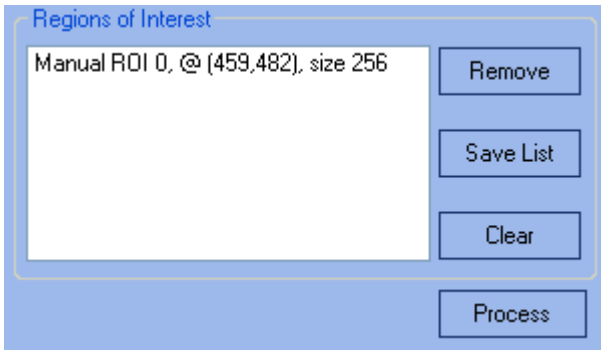
There are 3 ways to set the Regions of Interest. All of them start with clicking the Add ROI button within the Pattern Display Tab:-

1/ manually, left click in the pattern. Make sure that the corners of the resulting square are all within the pattern. It is best to avoid scratched areas of the phosphor when doing this.

2/ automatically, by selecting a number of ROI. These are positioned within the boundary defined with the New Boundary button. The ROI will be automatically resized if they are too big to fit within the boundary.

3/ finally, previously saved ROI lists can be reloaded using the Load button.

Once at least one ROI has been chosen, the ROI list appears on the Project page below the Reference list as shown.



The accompanying buttons are :-

Remove – removes the highlighted ROI

Clear – removes all ROI for the list

Save List – save the ROI to a text file with a '.ROI' file name extension.

Also shown in this panel is the Process button. This is visible at all times but will not allow progress to the process page until various criteria are satisfied – namely there is there is at least one item in the reference list , an ROI has been selected. If less than 4 ROI have been selected or the Material selection has not been completed (the Material button is red) then processing will stop after the pattern shifts have been measured.

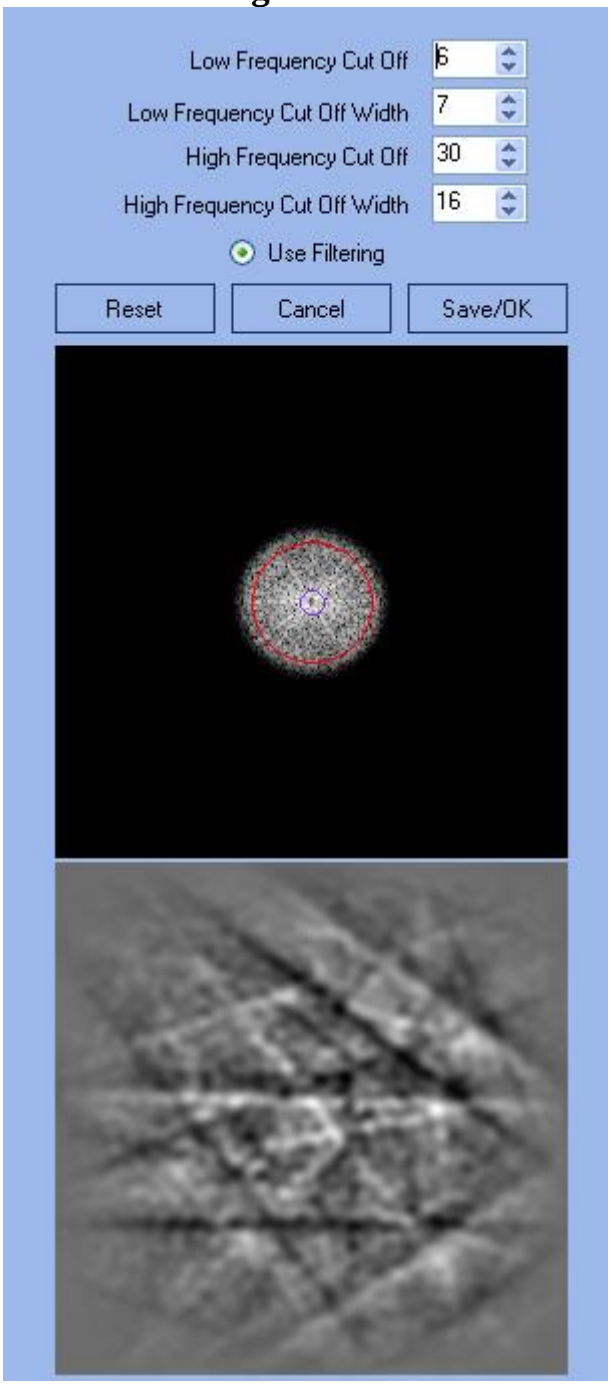
Before proceeding to Process the images the Filter settings must be appropriate for the images (section 3.7).

Once set and before proceeding to execute the analysis, the final step is to add all the regions of interest to be used to measure the pattern distortion. Click on the add ROI button again to show the options. It is normal to use the AUTO option and use the toggle to select more than 10 ROIs. Although only 4 ROIs are needed to determine the displacement tensor selecting

more means that the tensor can be determined numerous times and from all the results an average value can be obtained. Further statistics are also carried out and are used later to assess the quality of the reliability of the result.

It is also possible to select ROIs manually. The movement of particular zone axes can be followed using this option. Scratches on the phosphor can also be avoided by careful placing of the ROI.

3.7 Filter Settings



Click the Filter Settings button. Select an ROI towards the centre of the EBSD pattern and adjust its size so that it covers approximately 1/3rd of the image width. The left hand panel will now change to show the filter settings. Select an ROI again preferably centred on a zone axis in the pattern, 'point where many bands cross'. Both the Fast Fourier Transform (FFT), image and the back transform image appear in the left hand panel. The displacement calculations using a cross correlation function operates on the FFT of the image so it is important to set the 'cut off' values judiciously.

Each band in the EBSD pattern appears as a spike centred at the centre of the FFT and directed at right angles to the original band. The FFT diagram is a plot of Fourier component, i.e. its frequency, versus the intensity of that component, i.e. the brightness on the screen. The lower frequency components are towards the centre of the figure and the higher ones at the limits of the spikes. The higher frequency components carry information with respect to the sharp changes in the pattern whilst the low frequency components carry information as regards long range contrast changes. The spikes only extend part way across the FFT.

It is important to set the red ring shown in the figure so that it is just outside the longest spike seen. All Fourier components beyond the ring will be ignored in the calculations as they convey only noise in the EBSD pattern. The frequency of the cut off is displayed in the list at

the top of the panel. It is headed High Frequency cut off. The precise value can be altered using the tumbler controls. Below this setting is ‘High frequency cut off width’. This designates the range of frequencies beyond the red ring over which the contribution of that frequency component to the FFT is gradually reduced to zero. The expansion of the cut off width can be seen in the figure as an expansion of the FFT image outside the red ring. It is important to set this value to at least a quarter of the high frequency cut off value. It reduces artefacts or ‘ringing’ in the FFT.

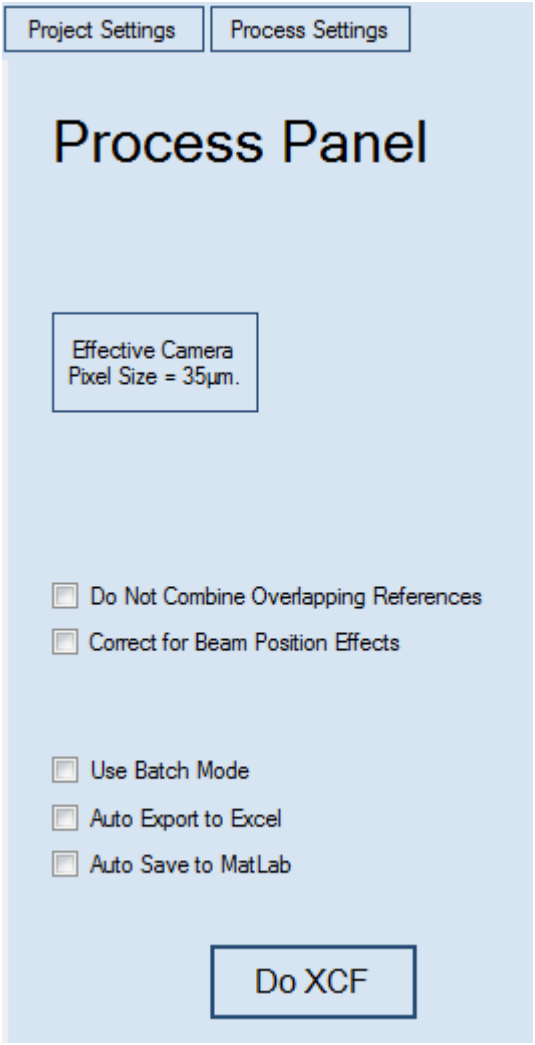
The low frequency cut off is set by using the tumbler control adjacent to the “Low frequency cut off” indicator. This controls the very long range frequency components which are responsible for blurring the EBSD image. It also acts as a flat fielding filter. The low frequency cut off width acts in a similar fashion to the high frequency width.

Try and set the low frequency cut off at a level where the overall pattern looks flattened with sharp lines delineating the edges of the bands.

Changing these setting should affect the noise level of the measurements.

The effects these settings have on the EBSD pattern can be followed by observing the lower EBSD image. This image is that part of the EBSD pattern within the ROI after it has been processed using the FFT filter. It is the back transform of the filtered FFT. The buttons Reset Cancel and Save operate in the manner implied by their label.

3.8 Process Panel



Once at least one reference and one or more ROI have been selected and the elastic coefficients have been assigned, the Process button on the Project Settings page can be clicked.

The Process button displays the Process Panel on the left hand side of the application. The Project Page can be re-shown using the Project Settings button at the top of the panel.

The Effective Camera Pixel Size = XXµm button sets the effective size of the camera pixel. This is used to correct for beam position effects. Instructions on how to measure the pixel size can be found in Section 5.4

The 'Correct for Beam Position Effects' checkbox is used to enable the beam position offset correction – This can be switched on or off at any time and the Results will be updated accordingly. See Section 5.4 for more details.

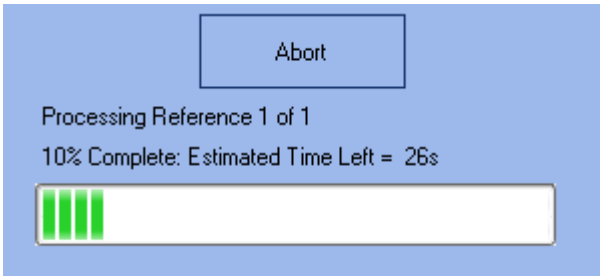
The 'Do Not Combine Overlapping references' tick box is concern with polycrystalline analysis and hence detailed in that section.

The 'Use Batch Mode' saves the project and a results file to 'blgx' format – no results are displayed. This is useful for processing very big datasets with lots of references. Results for each reference are saved as the analysis progresses.

The 'Auto Export to Excel' checkbox is used for exporting the results to Excel. When checked the results are exported as soon as the last reference is processed.

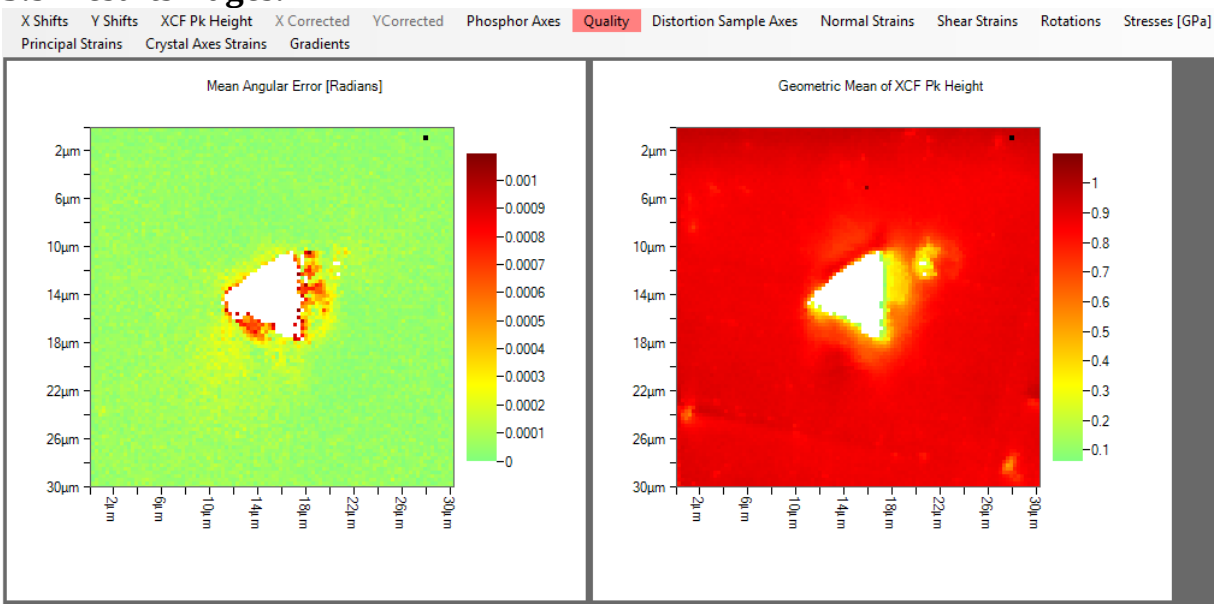
Similarly the 'Auto Save to Matlab' checkbox can be used to save the generated data to a '.mat' file – see Section 6.

Finally, and most importantly the Do XCF button is used to start the cross correlation processing. Once clicked it is replaced with an Abort button and a progress bar as shown below.



Each reference is processed in turn and the results are shown as each is finished. If the Abort button is clicked the process is stopped and the user is prompted whether to display or discard the partial set of results calculated so far. Please note it is unwise to restart the processing after aborting. Instead, we recommend saving the current project to Excel and then restarting the software and reloading the project. If you do restart, wait for the Display partial results dialog to appear before doing so.

3.9 Results Pages.



After the results are calculated they are displayed on the right-hand side of the application as shown above. The two displayed, by default, are the Mean Angular Error and the Geometric Mean Cross Correlation Function (XCF) Peak Height. These are defined below.

Results for each Reference pattern have a tab at the top of the screen. For each reference there is a lower toolbar (shown above) detailed as follows:-

- **X Shifts / Y Shifts**

  These show the results from the cross correlation calculations. There is a map or linescan panel for each ROI.

- **XCF Pk Height**

  This page shows the normalised Peak Height of the Cross Correlation function (XCF) between the reference pattern and the pattern from a particular point in the map or linescan. Again a map or linescan is displayed for each ROI. The better the correlation between the two ROI the bigger the XCF peak is. The values are normalised so that the Reference pixel has a peak height of one.

  Sometimes because the brightness of a pattern may be more than that of the reference pattern, the normalised value may be slightly more than one.

- **X Corrected / Y Corrected**

  These are the shifts after correction for the beam offset. Figures will appear here only if the 'Correct for beam shift effects' toggle was ticked on. If they are displayed all of the following results are based on these shifts. If they are not displayed the results are based on the raw shifts.

- **Phosphor Axes**

  This page shows the 8 components of the distortion matrix that can be calculated directly. They are presented with respect to a frame of reference in the Phosphor screen. Axis X_1 is horizontal, X2 is vertical and X_3 is normal to the screen. Initially, all the components are shown with the same colour scale range. These can be reset by right clicking on the map and choosing the 'Edit Colour Scale' context menu option. This page is only shown when 4 or more ROI have been used

© BLG Productions Ltd 2010

- **Quality, 'Mean Angular Error' and 'Geometric Mean of XCF Pk Height'**

  This is the initial page of the results that is displayed when the calculations are finished.

  The 'Mean Angular Error' map shows the back calculated errors for the distortion matrix shown in the Phosphor Axes page – i.e. the mean angular difference between the measured shifts and the 'back calculated' shifts from the distortion matrix. If only 4 ROI are used this calculation is null If more than 4 ROI are used the best least squares result is shown in the Phosphor Axes page and the Mean Angular Errors become meaningful.

  The 'Geometric Mean of XCF Pk Height' map is calculated by multiplying all the normalised XCF Peak heights for the ROI. The resulting number is a good indicator of the quality of the data for each point.

  Both of these maps can be used to set a threshold for the Results. For example if some pixels are exhibiting a large Mean angular error then it is possible the patterns taken at these points were poor or there was some artefact spoiling the results. Clicking on the scale bar at the values of the error will remove all data above or below this from the calculations as appropriate. Accordingly the data will be re –calculated without them. This is done as described above for the project maps. Any threshold set, only applies to the results data for the current reference. More details can be found in the Tutorials

  The Settings Menu has a 'Show Extended Quality Maps' option. When this is checked, a series of extra maps are shown. Firstly the Standard deviation (SD) of the MAE, secondly the ratio of the SD and the MAE and finally the back calculated angular error for each region of interest.

- **Distortion Sample Axes**

  This page shows the distortion matrix after being rotated into the sample frame of reference. . Axis X_1 is horizontal, X_2 is vertical and X_3 is normal to the sample surface. Additionally, the 9^{th} component of the distortion tensor is calculated using the elastic constants and the fact that the traction (stress) normal to the sample surface is zero.

- **Normal Strains**

  This page shows the three components of the normal strains, ε_{11}, ε_{22}, ε_{33}. The default settings are red positive (tension) and blue negative (compression).

- **Shear Strains**

  This page shows the three components of the shear strains, ε_{12}, ε_{23}, ε_{31}. The default settings are red positive (tension) and blue negative (compression). Note that as this is a symmetric tensor the additional components ε_{21}, ε_{32}, ε_{13} are equal to ε_{12}, ε_{23}, ε_{31} respectively.

- **Rotations**

  The distortion matrix for the sample axes can be split into the pure rotation and strain components by separating it into its asymmetric and symmetrical components. This page shows the three rotations, ω_{12}, ω_{23}, ω_{31}. The axes of rotation are X_3, X_1 and X_2 respectively.

Also calculated is the High Res Kernel Average Misorientation (HRKAM). The HRKAM is calculated by comparing the rotation of a given data point with those of its immediate neighbours. This gives very similar information to the standard KAM but with a precision of better than 1/100 of a degree.

The units of the rotation maps can be switched using the Settings menu.

- **Stresses**

  This page shows the Stresses in the sample axes as calculated using the Elastic Coefficients and the crystal orientation. The Mises Stress is also calculated.

- **Principal Strains**

  For any combination of Shear and Normal strains there exists a frame of reference in which the strain matrix reduces to purely Normal strains. These are called the Principal strains and the frame of reference is called the Principal Axes.

  CrossCourt calculates these and displays them. However, at this moment the maps are not perfect. For a given data point 3 principal strains and axes are calculated, but it is not trivial to line these up with the principal strains/axes of the neighbouring data points.

  Currently, CrossCourt orders the strains so that the first principal strain is the most tensile and the third is the most compressive. This works well some of the time but is not a perfect solution. Often the 2 weakest strains are mixed up.

  Similarly, the maps of the Principal axes are not ideally plotted. A given axis may be in any direction but for plotting purposes these are reduced to the unit IPF triangle.

- **Crystal Axes Strain**

  In this set of results, the symmetrical strain matrix (rotations removed) is rotated around into the crystal axes system (i.e. 100 010 & 001) and its components are displayed.

- **Gradients**

  This page shows the partial gradients of the rotational components in radians per micron – (never degrees per micron).

  Each rotational component is differentiated with respect to the X_1 (δx) and X_2 (δy) axes. Unfortunately it is not possible to differentiate with respect to X_3 (δz).

- **GND's**

  Crosscourt 3 allows the calculation of the numbers of Geometrically Necessary Dislocations (GND) necessary to create the rotation gradients measured above. This number is a lower limit estimate, because a/ CC3 is not able to produce the rotation gradients with respect to X_3 (δz) and b/ there are generally more slips systems present in a crystal than there are degrees of freedom for the crystal to deform (9 gradients of which 6 are available). As such a lowest energy solution is found.
  Please note that this calculation is more complex and hence slower than others in the software; when entering this page of results, note the progress bar at the bottom left of the application – no results will be shown until this is at one hundred per cent.
  GND values can currently be calculated for FCC, BCC and Hexagonal materials. If you have an interest in looking at a GNDs in a crystal of a different symmetry please let BLG Productions know including a list of the slip systems found in that crystal

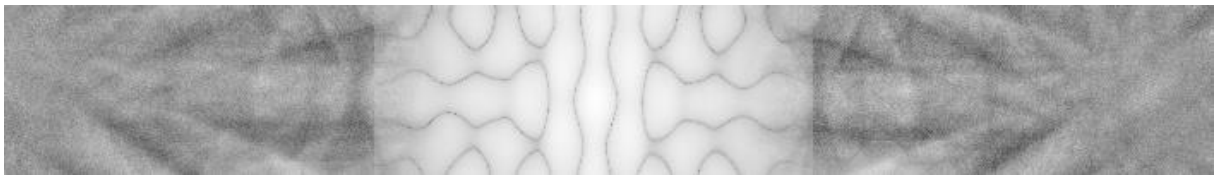
symmetry and we will endeavour to add them.
Maps of the total GND density, totals of Edge & Screw GND densities and maps of the GND numbers for individual slip systems are produced.

3.10 Display Page

The data display page is selectable once the XCF calculations have finished, using a button which appears just below the main form menu.

Once the page is selected, use the mouse cursor to hover over any of the data points in the maps or linescans. The data display page will show a synopsis of the information about that data point.
The top display shows the unit cell including the measured distortion and the bottom display shows the principal strains and their axes.
The distortion multiplier control adjusts how much the distortion is magnified when applied to the wire frame unit cell.

Section 4 – The Polycrystalline Case.



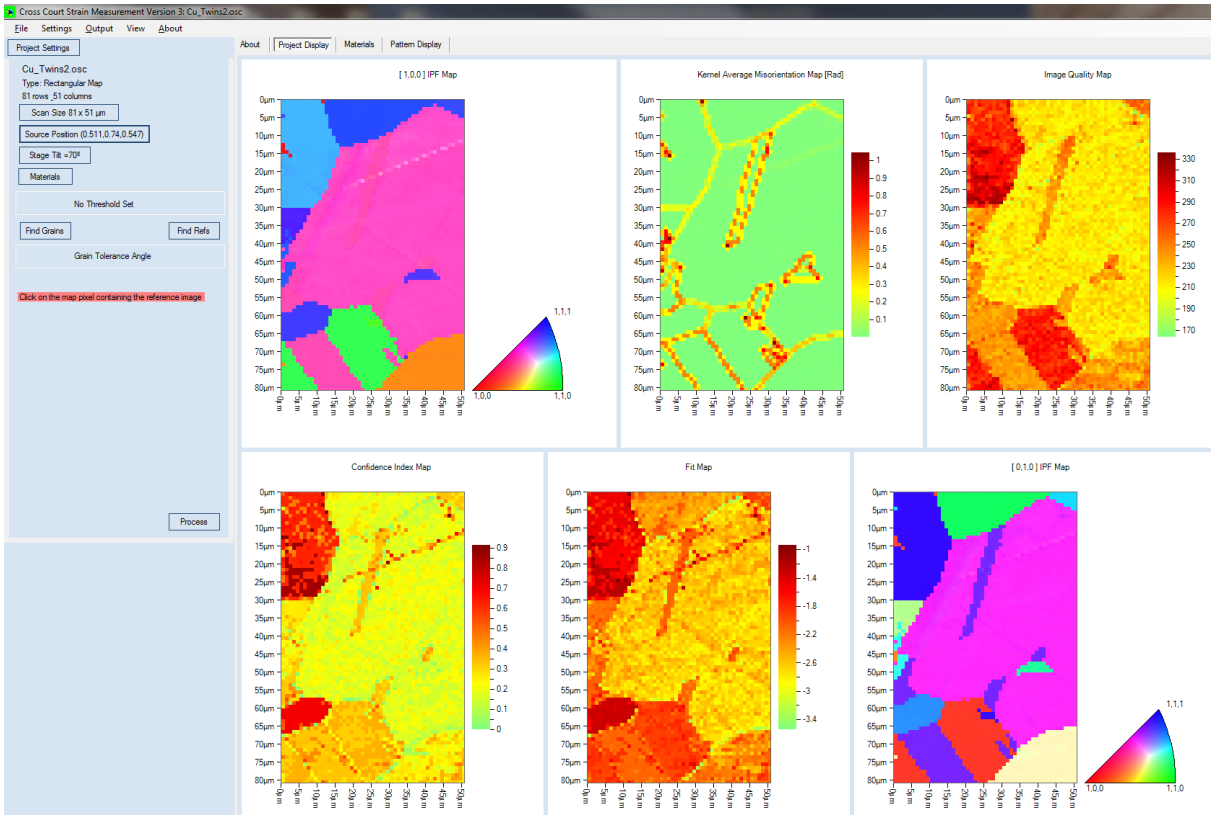
4.1 Finding Grains.

In the polycrystalline case we have to face the problem that we cannot use cross correlation to measure the differences between patterns from radically different orientations, because the ROI will contain completely different information to each other. As such each Reference pixel is only valid for comparison with pixels of ‘similar’ (see Section 4.2) orientation.

A second problem occurs in the polycrystalline case – finding an area that can be assumed to be strain free is now much more difficult.

CrossCourt 3 uses a measure called the ‘Grain Tolerance Angle’ to define a grain and contains a range of tools to assist with choosing a suitable reference.

The polycrystalline settings are input in the ‘Project Page’



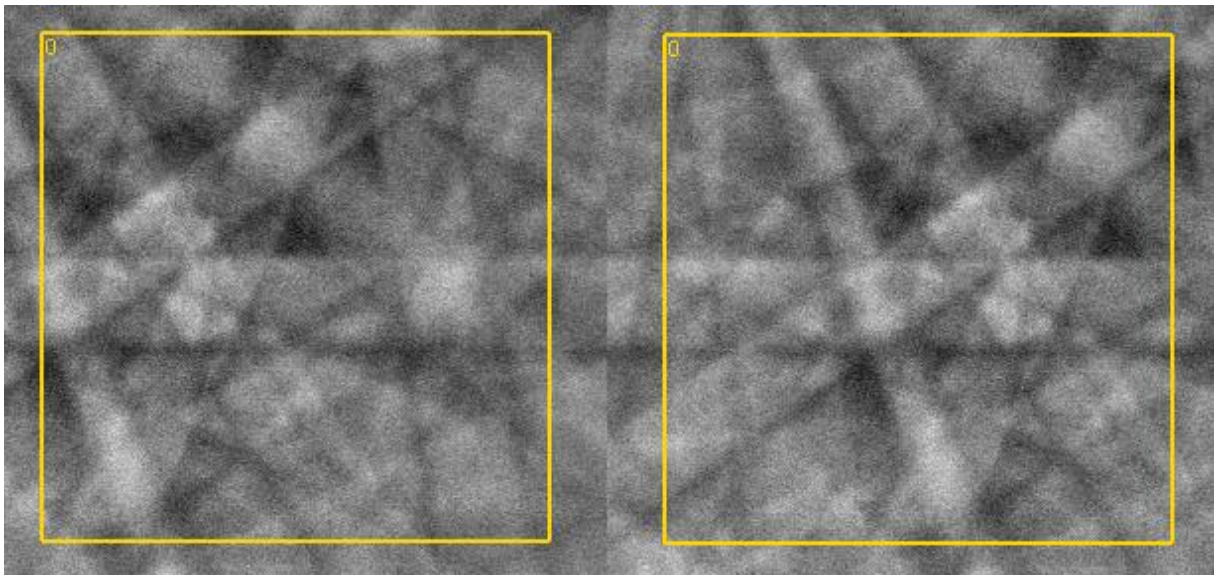
On loading the project file the default maps as described in Section 2.2 appear. They do not include a grain map. It is necessary to create a grain map because the cross correlation method only works if the patterns from the strained region are close in orientation to the reference pattern. In Crosscourt 3 we define ‘close in orientation’ using a measure called ‘the Grain Tolerance Angle’ or GTA.

© BLG Productions Ltd 2010

4.2 Grain Tolerance Angle

The Grain Tolerance Angle (GTA) is used to define a set of pixels that can be compared with a reference of a particular orientation.

Cross Court works by comparing an identically positioned ROI within two EBSD patterns; one obtained from a reference point in the sample and the other from a test point. Obviously, if the crystal contains highly disoriented regions, where the test point is rotated with respect to the reference point by an amount greater than the angle subtended by the ROI, then the content of the ROI will be completely different in the reference and strained cases and hence cross correlation cannot be used to compare them. Thus, as the rotation between reference and test pattern increases, the amount of overlapping pattern decreases as does the quality of the cross correlation



This is illustrated in the two images above. The amount of overlap between the two images is small thus the cross correlation quality suffers.

The maximum angular difference (i.e. the GTA) suggested by the software is about 1/4 of the total angular range across the ROI.

When the Find Grains button is clicked the Grain Tolerance Angle dialog is shown with this suggested value - the user is free to alter the values if thought necessary.

If the find grains button was not activated then the set Angular tolerance window only become active once an ROI has been selected in the project display window and this in turn requires prior selection of an EBSD pattern. This is done by clicking on one of the maps shown and clicking show in the reference list.

Clicking the Set Tolerance button will launch a dialog box in which a maximum safe tolerance will be suggested. This is the angle subtended by 1/4 of the ROI width as seen from the electron source.

4.3 A Note about Grain Definitions

Crosscourt 3.0 used the GTA to define a grain as the collection of data points that have orientations within the GTA of the reference orientation. This collection was not necessarily contiguous and had little in common with more traditional grain definitions.

A more standard grain definition is one of a contiguous set of data points bound by a step change in orientation of more than a certain angle. That is to say every point within the grain will have an orientation within that angle of its immediate neighbours.

This is the grain definition now used by Crosscourt 3.1 – the angle in question is the GTA. The change that has allowed this is the use of more than one reference point per grain.

In the new system the problem then becomes; how do we relate the references to one another in a single grain?

Imagine the situation where a grain is bent into a gradual curve such that the orientation at one end of the grain is disorientated from the other end of the grain by more than the GTA. In the old system the 2 ends of the grain would be 2 different grains because at least 2 references would be needed.

Consider 2 references A & B in the same grain (as defined for CC3.1) that are separated by a disorientation that is more than the GTA but not more than twice the GTA. Because they are in the same grain we can be sure that there will be a set of one or more points in the grain that have orientations within the GTA of the orientations of *both* references. I.e. there is always overlap between the two references – because of the definition of the grain used. If there was no overlap – the references would be in separate grains by definition.

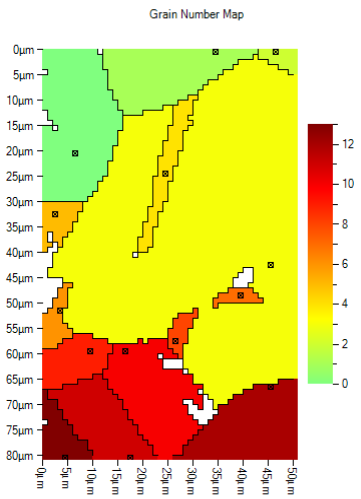
Next, consider a point O in the overlap region. Point O has a measured shift with respect to A of say S_{OA} and say of S_{OB} with respect to reference B.

Hence the shift between A and B can be calculated as $S_{AB} = S_{OA} + S_{OB}$. Where there is more than one point in the overlap, an average is taken.

Once the shifts between the references are calculated, all the data measured w.r.t. reference B can now be assigned to reference A.

This is clearly a linear approximation and it will become less accurate as the extent of the bend across the grain increases.

Note, it is possible to override the automatic combination of references from the same grain by ticking the 'Do not combine overlapping References' Checkbox on the Process Panel.



It is normal when analysing polycrystals to use the find grains button and accept the displayed grain tolerance angle. When this is done a grain map is added to the already displayed maps.
Each grain is assigned a number starting at zero. The number for any grain is displayed above the map and changes as the mouse cursor is moved into another grain.
In addition the Settings menu contains a Minimum Grain Size option. This number is the minimum number of data points in a grain necessary for that grain to be included. The default value is two. The map displayed on the left has the minimum number of points set to 20.

© BLG Productions Ltd 2010

4.3 Find References

It is possible to select the reference pattern to be used for each grain manually. Alternatively the Find Reference button can be clicked and they will be found automatically. A dialogue window opens asking for the criterion to be used in selecting the reference pattern. The options are, Kernel Average Misorientation, Image Quality, Confidence Index and pattern Fit. These parameters are determined in the data collection software used. We currently recommend using the Kernel Average Misorientation (See the tutorials for an expanded discussion of this).

It is important to note that the reference pattern selected will probably not have zero strain. It is only the best pattern observed with the criteria selected. All strain values measured with respect to it will therefore be relative to it. If the reference grain is in tension for example, the true strain for all other measurements will be the measured strain plus the strain of the reference pattern. All measured rotations are with respect to the actual orientation of the reference grain.

The reference patterns will then be found automatically and distinguished in the maps by a cross within the data point. If the first selected reference cannot be used for the whole grain, additional references will be selected.

It is still necessary to set the Boundary, ROI and Filter settings, as for the single crystal case.

Once the references are selected, continue to determine the strain by selecting Process and progressing to Do XCF.

Once the Grain Tolerance Angle has been set the behaviour of the software changes slightly.

The data for each reference is processed separately. References from the same grain are combined as described above, once calculated. After each grain/reference is processed the Data Quality maps are displayed/updated.

If the 'Use Batch Mode' tick box on the Project panel is ticked, the results for each reference are saved to disk upon calculation. The results are not displayed – but can be reloaded using the load BLG Project option.

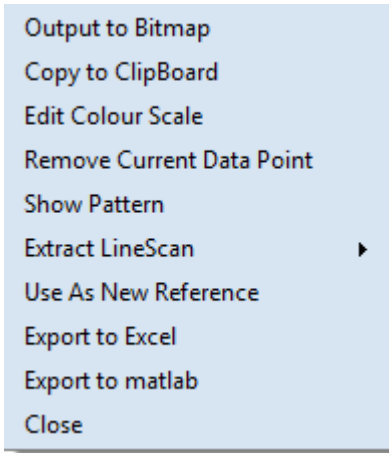
After processing the Combine Results button appears on the Process Panel. Clicking it transcribes all the data onto a single data set. This is purely for display purposes only, as comparisons between different references are not strictly valid (though misorientation and gradient information is relevant). Please note that when you change the data (e.g. displaying in Degrees rather than Radian, changing the pattern centre, elastic constants, etc.) you will need to re-press the Combine Results button to update the combined data display.

If the results for a single grain are to be studied they can be selected by clicking on the tab labelled with its reference pattern.

If you have navigated away from the Process, and you wish to view combined grains again then scroll to the very right hand side of the top menu where you will find the Combined Results button again.

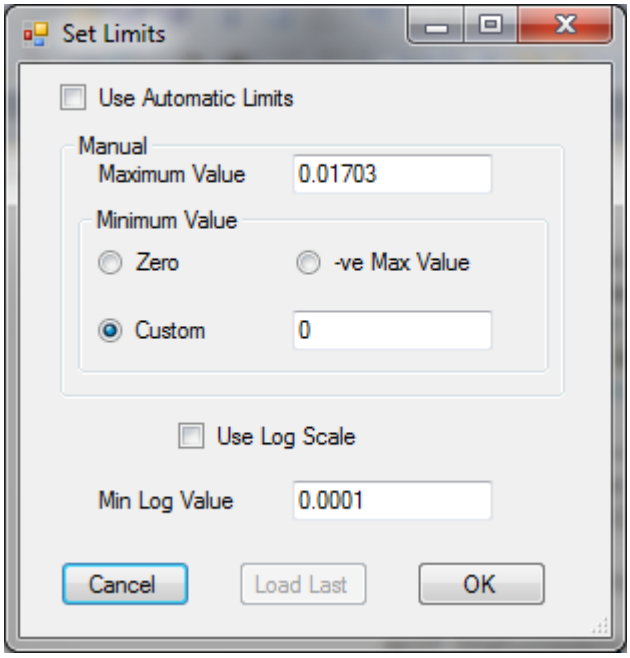
Section 5 – Additional Functions

5.1 Right Click on Map context Menu.



When a map is right clicked (a subset of) the menu shown on the left is displayed. Each option is considered in turn below.

- '**Output to Bitmap'** – Click this to save a bitmap of the map to file.
- '**Copy to ClipBoard'** – the image of the map is saved to the Clipboard.
- **'Edit Colour Scale'** – Clicking this displays the Set Limits dialog as shown.



Use the dialog to select a range of values and click OK. Ticking the 'Use Automatic Limits' checkbox uses the maximum and minimum values in the dataset to define the colour range.

The Minimum Value Radio buttons can be used to set the minimum to zero or the –ve maximum value. Manually entering the minimum value will automatically select the Custom radio button.

If (as shown) the range straddles zero, a colour range of ± the maximum absolute value. E.g. in the example shown a scale of ±4.55 will be used. This is so that zero is always green.

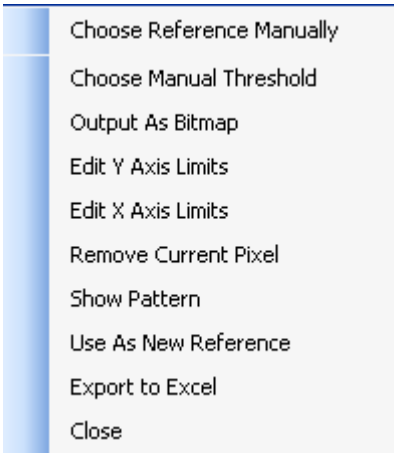
The 'Use Log Scale' checkbox is self explanatory, but the 'Minimum Log Value' is not. This value is the number, below which data is coloured green (i.e. equated to zero). As the log of zero is –Infinity, this allows data that contains both positive and negative values to be plotted (essentially on different colour scales). For presentation purposes this value makes a huge difference to how the data is displayed; too small a value and the data will appear mostly red and blue in the standard HSV colour scheme, too large a value and low

values will not be displayed at all. If the colour scale is entirely positive, this value is not used.

The Load Last button loads the last colour scale selected – it can be used to apply the same colour scale to a series of maps.

- '**Remove Current Pixel'** – This is used to remove the data point that was clicked on from the dataset. It will not be used when calculating strain values.
- '**Show Pattern'** – This option displays the EBSD pattern associated with the clicked data point. The display changes automatically to the Pattern Display page.
- '**Extract LineScan'** – This opens into a choice of Horizontal or Vertical linescans in the case of a Rectangular Scan (Only Horizontal available for the Hexagonal Scan). Choosing one of these extracts a linescan going through the pixel that was clicked. The Linescan is displayed on a new (right hand) tab called 'Custom Results'.
- '**Use As New Reference'** – This option is only available for use on single crystal results or when only a single grain in polycrystalline sample is displayed. The shifts from the chosen data point are subtracted from the measured shifts for all other data points in that grain. All strain and stress data is then recalculated. This technique should be used sparingly as there will be a loss of accuracy (any noise on the subtracted shift measurements is transferred to all data points).
- '**Export to Excel'** – this option exports the values in the displayed map directly into Excel. No supporting information is exported.
- '**Export to Matlab'** – Similarly this option outputs the map data into Matlab – the matrix saved will have the name "userdata".
- '**Close**' – This Closes the current map.

5.2 Right Click on Linescan Context Menu.



When a linescan is right clicked a subset of the menu on the left is shown. These options are mostly similar in functionality to those found on the Map context menus.

- **'Choose Manual Reference'** – This option brings up a dialog box designed to allow the user to enter a reference by number – where 0 is the first point on the linescan, 1 is the second, etc, etc. This option is made available because it can be difficult to choose a reference by left clicking near the axes.

- '**Choose Manual Threshold'** – Similarly, this option allows the manual entry of a threshold value using a special dialog box.
- '**Output to Bitmap'** – Click this to save a bitmap of the linescan to file.
  'Edit Y Axis Limits' – This option displays the Set limits Dialog as shown in the previous section. Any range can be entered as long as the maximum value is greater than the minimum. These limits are applied to the Y/value axis of the linescan.
- **'Edit X Axis Limits'** – This option is identical to the above, but changes the data points displayed on the X axis instead.
- '**Remove Current Pixel'** – This is used to remove the data point that was clicked on from the dataset.
- '**Show Pattern'** – This option displays the EBSD pattern associated with the clicked data point.
- '**Export to Excel'** – this option exports the values in the displayed linescan directly into Excel. No supporting information is exported.
- '**Close'** – This closes the current linescan.

5.3 Menu Items

- **File | Load Project**.
  This option replicates the functions of the 3 Load Project buttons as shown when the software is first started.
- **File | Load Folder**.
  This option allows the user to select a folder containing images that are not necessarily part of a project. All images in the folder are loaded. See the section "Load images from Folder' for more information.
- **File | Close Current Tab**
  This option closes the currently visible results page on the right. All data associated with the results is discarded.
- **Settings | Minimum Grain Size**.
  This number is the minimum number of data points in a grain necessary for that grain to be included. The default value is two.
- **Settings| Camera Elevation Angle**.
  This value is used when correcting the pattern shifts for position offsets. Camera tilt is the elevation of the camera tube from the horizontal. +ve when the camera is pointing upwards, -ve for tilts when the camera is facing down. It is used in combination with the specimen tilt to allow the correct rotation of reference axes from the screen to the specimen.
- **Settings| Change Colour Scale**
  Allows the user to change the style of look up table (LUT) used to display the map data.
- **Settings| Show Euler Maps**
  Toggles the display of the Euler maps on the project maps panel.
- **Settings| Show IPF Maps**
  Toggles the display of IPF maps on the project maps panel. These maps are with respect to the cubic axes of the sample, not w.r.t. the directions in the crystal system.
- **Settings| Use Degrees & Settings| Use Radians**
  These linked settings change the angular units used by the KAM and other rotation maps. The units of the Gradient maps are always in Radians/micron.
- **Settings | Show Extended Quality Maps**
  Displays extra maps on the quality tab as discussed in Section 3.9.
- **Output | Export As BLG Project to Excel**
  This option is only enabled after a project has been loaded. Selecting this starts an instance of Excel and outputs the current data set to it. Maps of more than 255 columns require Excel 2007 or later. All project data is saved as well as all the shift data for all the references and the calculated strains and stresses. Combined & Custom Results are not output – they can be output to Excel by right clicking on the individual map/linescans.
- **Output | Output As Bitmap**.
  This option creates a bitmap containing an array of all the currently displayed maps/linescan panels. The user is prompted for a filename.
- **Output | Export as Matlab File**
  This option outputs the data to an '.mat' file to allow further processing in Matlab. Data is

exported in MAT-File 5 format. This format is very useful when very large amounts of data are collected as Excel files can become overly large.
Note: Hexagonal Scans. can not be exported to Mat-File format

- **Output | Export BLG Project**
  This outputs the current data in a blg file format.
- **View**.
  This menu allows the user to choose a particular right hand tab from the list for display.
- **About.**
  This option shows a dialog containing information about the version number etc of CrossCourt.

5.4 Beam Shift Calibration

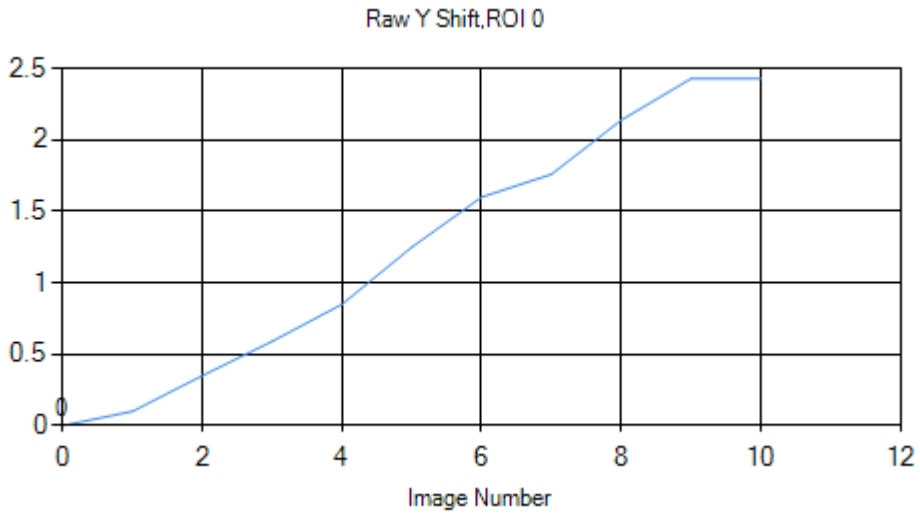
Introduce into the SEM a clean single crystal of silicon, or germanium for example, and set up the microscope, specimen stage and beam conditions for obtaining high quality EBSD patterns. Set the EBSD camera to high resolution mode and adjust exposure time accordingly.

Adjust the specimen with respect to the beam x traverse so that the x traverse trajectory lies exactly parallel to the X axis of the phosphor. This can be difficult to do. However with patience using the following procedure the correct condition can be reached.

Observe the sample at 1000 x magnification. Set up a line scan of length 100 microns and step size 5 microns. Carry out the scan recording the pattern at each step. (You will have to turn on the record images function of the data collection system and set type to tiff). Save to file.

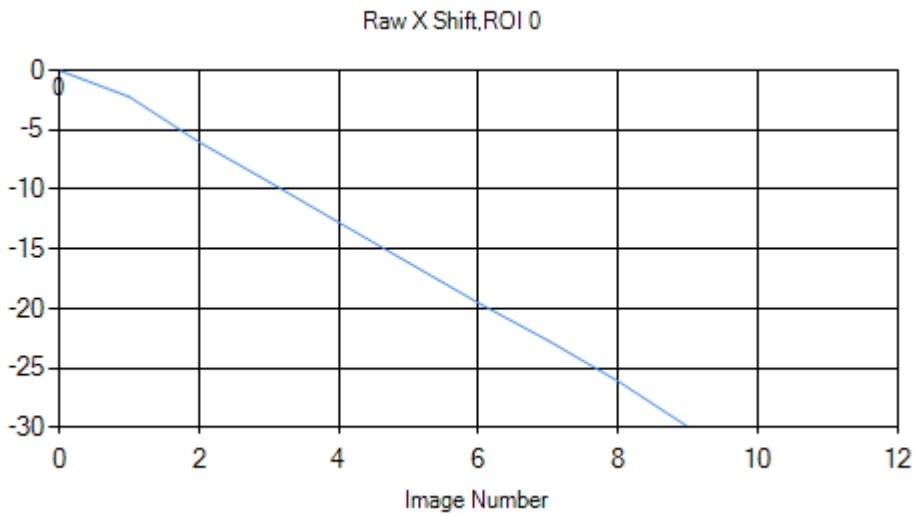
Open Crosscourt3 and load the file. Carry out the software set up as described above. Set the reference at the first point and manually select a single ROI and position it at the pattern centre. Do XCF. The data will be a line scan of shifts. The output will first show the Mean angular error and the Geometric mean height. The range of the mean angular error, excluding the first data point should be of the order 0.0002 radians. The exclusion of the first pixel is because this value is forced to 0.

Examine the Y shifts. They should appear as in the figure.



If as shown there was a shift in the Y direction of more than 1 pixel then in this case the beam rose up the specimen surface as it moved across it. The specimen should be rotated about the beam axis to correct for this and the data retaken until the Y shifts are below 1 pixel for the entire scan.

When this is achieved then examine the X shifts.



The total pattern shift was 30 pixels in 9 beam steps. In the case shown the actual distance moved by the beam was 900 microns. The Pattern therefore moves 30/900=0.033 camera pixels per micron. Or to put it another way each pixel in the camera sees an area of 30.3 µm x 30.3 µm. The effective camera pixel size in this case is 30.3 µm.

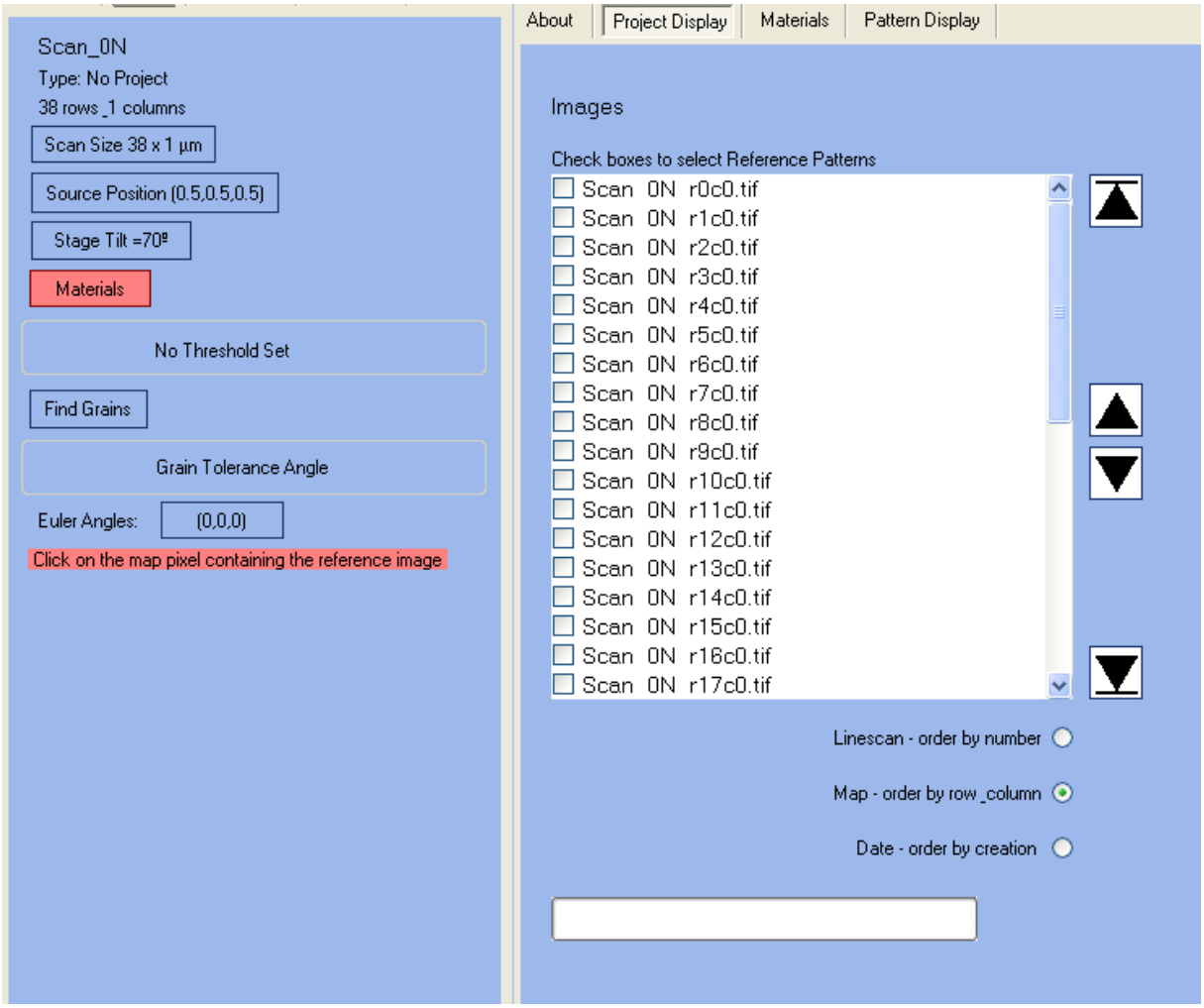
Use the Effective Camera Pixel Size button on the Process Panel to input this value into the software. The value is remembered between different software sessions. The result is independent of the camera position, the pattern centre, the scan size or the step size. Recalibration is only necessary if the camera set up is changed i.e. if the distance from the camera to the phosphor screen or the camera focus on the phosphor screen is changed.

5.5 Load Folder

The ‘Load Folder’ menu item gives the user the ability to process a group of images that are not connected by an associated project file.

All the images should be in a single folder.

Selecting ‘Load Folder’ starts an Open Folder Dialog. Use the dialog controls to select the folder containing the image and Click OK.



The Project panel is shown along side some new controls based around a list of image names.

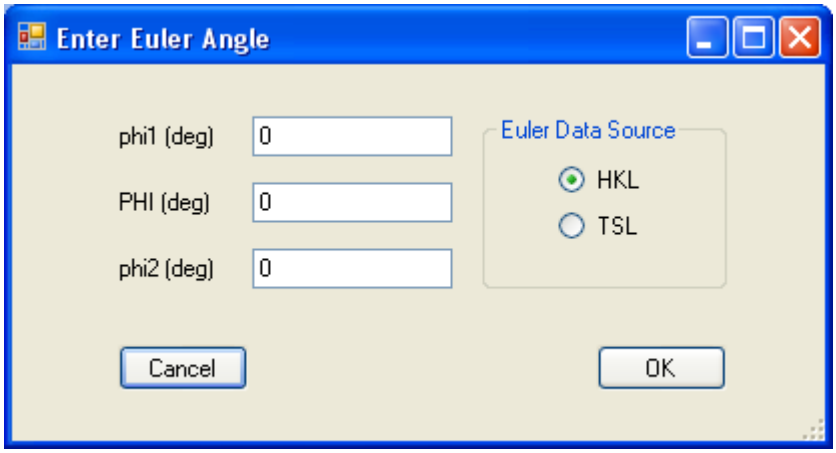
Click once on an image name to select the image, Double Click to choose as a reference.

The images can be rearranged using the radio buttons below the list.

Once an image is selected a Remove Pattern Button becomes visible – use it to remove the currently selected image from the list. A Selected image can also be moved up and down the list using the arrow buttons.

The behaviour of the Project Panel is also slightly different to the situation when a project is loaded.

The Source Position must be entered and the Materials set. Also Euler angles for the images must be entered. Cross Court 3 assumes all images have the same Euler Angles. Click the Euler Angles button to manually enter the Orientation using the Euler Angle Dialog Box:-



If the Euler angles are from EDAX_TSL software, check the TSL Euler Data Source radio button. This is necessary because Cross Court 3 uses a different reference system to EDAX_TSL. Correcting this is done by the software if the TSL option is selected. Essentially, 90º is added to the value of phi1.

Once a reference image is selected, the software can be used as normal. The data is treated as a linescan with a default step size of 1µm. This can be altered using the project panel controls (Section 3.1).

6. Matlab Data Structure for CC Analysis

Introduction

The following file lists each of the variables used in CC analysis as output in the Matlab format. The indexing is outlined as used in Matlab.

Project Details:

Variable Name	Type	Description
numrows	integer	Number of rows in data set
numcols	integer	Number of columns in data set
numphase	integer	number of phases in project file
numims	integer	Total number of images in project
imhig	integer	Height of EBSD image in pixels
imwid	integer	Width of EBSD image in pixels
pixelsize	double	Effective size of camera pixels in microns
stagetilt	double	This is the effective tilt angle between the phosphor and the sample surface.
xstep	double	X direction Step size in microns
ystep	double	Y direction Step size in microns
roisize	integer	Size of the Regions of Interest in pixels
numroi	integer	Number of ROI used in analysis
numref	Integer	Number of References used
pcfrac	1x3 array of doubles	centre as a decimal fraction [X*,Y*,Z*]
stiffnessvalues	3dimensional array of doubles	Contains stiffness values for each phase indexed as [6,6,phasenumber]
phasetxt	Array of strings	Contains phase names
roiloc	2 dimensional array of doubles	Array contains ROI centres indexed as [roinumber,2] with each line of the form [roixloc, roiyloc]
confidence_index_map euler_phi_map euler_phi1_map euler_phi2_map fit_map grain_number_map image_quality_map kernel_average_misorientation-map_rad xpos_map ypos_map phase_index_map	2 dimensional array of doubles	Arrays containing Project Data angle as read from project file indexed as [ypts,xpts]. If no data exists for a particular data type the information is not included. Euler angles are in degrees.

Project Details continued:

filters	1x4 array of doubles	Contains filter settings [high frequency cut off, high frequency cut off width , low frequency cut off , lf cut off width]
refloc	Array of Strings	Each array element is a string containing the name of the reference image followed by the position of the reference as a number from 0 to numims
version	String	The version of Cross Court used.
voltage	Double	SEM voltage in KV
date	String	Date of Processing
projectname	String	Name of original Project File
scanformat	String	Description of Scan format – i.e. Rectangular or Linescan
imagedir	String	Path of Directory containing EBSD images

Results*:*

Results are only exported if they have been calculated.

Variable Name	Type	Description
shiftsx shiftsy peakhgts corrshiftsx corrshiftsy	Cell array of 3 Dimensional arrays of doubles	Cell array indexed as [refnum] containing results of the cross correlations in a set of 3D arrays. Each is indexed :-[ypts,xpts,roinum]
dataph	3 dimensional array of doubles	Indexed as [ypts,xpts,refnum] and containing geometric average of normalised cross correlation peak heights of all ROI
dataerror	3 dimensional array of doubles	Indexed as [ypts,xpts,refnum] and containing mean angular error.
distsem	4 Dimensional array of doubles	Indexed as [ypts,xpts,1:8,refnum] containing the elastic displacement gradient tensor, as calculated in the phosphor frame of reference. The 1:8 elements are in the following order:- [A11-A33, A12, A13, A21, A22-A33, A23, A31, A32]
distsamp	4 Dimensional array of doubles	Indexed as [ypts,xpts,1:9,refnum] containing the elastic displacement gradient tensor, as calculated in the sample frame of reference. The 1:9 elements are in the following order:- [A11,A12,A13,A21,A22,A23,A31,A32,A33]
datarots datashears datanorms	4 Dimensional array of doubles	Indexed as [ypts,xpts,1:3, refnum] containing the Normal, Shear and Rotational components of distsamp. The 1:3 elements are indexed as:- [w12,w23,w31], [e12,e23,e31] and [e11,e22,e33] respectively.

datastress	4 Dimensional array of doubles	Indexed as [ypts,xpts,1:7,refnum] containing the stresses calculated in the sample frame of reference. The 1:7 elements are in the following order:- [S11,S22,S33,S12,S23,S31,Mises]

With thanks to Ben Britton.